Implementation of Semi-Autonomous Vehicle for Environmental Feedback

Senior Design Proposal
Fall 2003

Submitted to Dr. B.C. Chang, Dr. H. Kwatny and the Senior Design Project Committee of the Mechanical Engineering Department at Drexel University

Team Number:
MEM-22

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Abstract

In a world marked by war and terrorism, the Department of Defense has found an increasing need for the use of unmanned ground vehicles (UGV) to facilitate the safety of its soldiers in the battlefield. UGVs can be used for scouting and surveying enemy territory instead of placing soldiers at risk. In response to this matter, the objective of this report is to propose a design for a microcontroller based vehicle that can give the user feedback on the environment. We propose to implement a camera sensor on a vehicle that will be used to track and follow a marked line on the ground. Additional information including direction and speed of the vehicle will be recorded using magnetometer and accelerometer sensors, respectively. The direction information is needed to give the user an idea of the vehicle's orientation. The speed information is needed to control the response of the motors based upon the type of ground topography (e.g. sloped surface vs. flat surface). The goal of the project is to implement the combination of these three sensors (camera, magnetometer, and accelerometer) for better control of the vehicle in its environment. The intended deliverable will be a small vehicle powered by a rechargeable battery and controlled by the ATMega16 microcontroller. The vehicle will also contain the accelerometer, magnetometer, and camera sensors.

Table of Contents

I. Introduction

A. Problem Background

This project is a continuation of a 2002-2003 Senior Design under the guidance of Dr. B.C. Chang. The project involved a vehicle that followed an assembled line path (i.e., a line that is made of black electrical tape). The vehicle, made by Lynxmotion, was a 4-wheel robot basic kit with four 7.2 VDC 50:1 motors (Appendix E). The vehicle utilized a line sensor (Lynxmotion Line Tracking Sensor) that consisted of an array of three integrated circuits, each composed of a LED and an infrared detector. Signals from these sensors were fed back to an Atmel AT90S8515 microcontroller. The information was processed and an appropriate motor feedback control was applied to guide the vehicle along the line. Another objective of last year's design was obstacle avoidance. This was achieved by implementing sonar sensors on the front of the vehicle. This was the only vehicle guidance system that was used in the vehicle design.

B. Problem Statement

Issues concerning the previous year's design involved the line following algorithm and obstacle avoidance. One problem was that the vehicle did not provide feedback for velocity and acceleration. For a real world application, the vehicle will encounter different kinds of terrain variations causing fluctuations in velocity and acceleration. The issue with the line following sensor is that its functionality is limited to following a marked line. The vehicle's motion in line following was not smooth because the three infrared line following sensors were implemented using Boolean, or on-off control, causing the vehicle motion to become very "jerky" as it moved along the line. The problem with sonar sensors is that the information received is limited in its functionality. It only determines whether or not an obstacle is present in front of the vehicle. The vehicle was able to sense the obstacle from the sonar sensors and would stop before hitting it, but it could not maneuver around the object. Another problem was that the vehicle did not provide feedback for direction. Direction is an important component to inform the user where the vehicle is moving.

C. Design Constraints and Feasibility Study

As is the case with many design projects, our design will encounter various constraints. Several important issues to address are: (1) Integrating the accelerometer and magnetometer sensors to work with the ATMega16 microcontroller. In this case, the constraint is the high cost of the magnetometer sensors due to its complexity and small size. (2) Integrating the camera sensor to work with the ATMega16 microcontroller. A camera sensor would involve the background of image processing. The problem at hand is to figure out how to relay the camera sensor data to the computer for processing and then sending the data back to the microcontroller (on the vehicle) for proper reactions to the environment (3) Creating a graphical user interface to read sensor data. An interface needs to be created to accommodate functionality as well as ease of use. This will involve learning how to use a programming language such as Microsoft Visual Basic.

In spite of the constraints, the project is still feasible due to the resources available to the design. Resources such as the software and hardware in the MEM controls department allow the progress of this type of research. On-going research from Dr. Chang and his teaching assistants have provided up-to-date and cost effective equipment. Furthermore, the current availability of materials required for the project (vehicle chassis, microcontroller, sensors, electrical components, tools, and software) facilitates economic feasibility due to a significant reduction of the total cost to the project.

D. Related Work

Current research has revealed that there are various projects relating to line following using camera sensors and computer vision. One such project has been performed by the Robotics Institute at Carnegie Mellon Institute. This project involves a sensor called CMUcam Vision Sensor which can track the position and size of a colorful or bright object [1]. There has also been research in the area of visual control in autonomous vehicle following. Researchers from Texas A&M University have looked into the problem of vehicle-following using automatic steering and speed control. They also presented a model of their visual control system that involved image processing, recursive filtering, and command generation [2].

There has also been research in the area of wireless data links and control algorithms for remotely controlled vehicles. The University of Illinois has been working on a design to implement reliable two-way wireless communication between a control system and a remotely controlled vehicle with an attached camera. Their objective was to use this system in future control systems labs.

II. Statement of Work

A. Method of Solution

Enhancements will be made to the previous year's design to account for the issues mentioned in the Problem Statement section. The proposed design will re-use the Lynxmotion vehicle chassis and the project objective is to add three new capabilities to the vehicle: (1) Acceleration and velocity feedback (2) Direction and orientation feedback (3) Object tracking. To perform the stated functions, the design will comprise of five key components:

1. ATMega16 Microcontroller
2. Accelerometer
3. Magnetometer
4. Camera Sensor
5. Program Software

ATMega16 Microcontroller

The microcontroller will be upgraded from an Atmel AT90S8515 microcontroller to an Atmel ATMega16 microcontroller. The ATMega16 has two times the clock speed and a built-in analog-to-digital converter (Appendix G). The microcontroller will play a vital role in processing the data coming from the accelerometer, magnetometer, and camera sensor.

A discrete 1.75" x 2.75" circuit board will be created containing the ATMega16 microcontroller and its operating components such as power supplies and clock. This small circuit was designed to fit into the compact vehicle. A 6-pin header will also be on this board so that programming can be done via ribbon cable from the STK500 development board. This was done to eliminate moving the microcontroller chip from the STK500 board to our circuit board during programming. The STK500 is a microcontroller development board made by Atmel for use on their microcontrollers. It contains digital I/O ports and a RS-232 interface to PC for programming and control [3].

Contact pins connected to all of the microcontroller signals will be included on the circuit board. From these pins, we will be able to connect the various H-bridge circuits, transceiver circuits, and sensors to the microcontroller. Electrical schematics of this board and its connections are located in Appendix F.

One primary power supply (7.2V 1700mAH NiCad battery-pack) will be used to power the electrical components of the rover. From this main supply, it will feed two voltage regulators that will provide a reliable 5V and 7.2V supply. This will become our secondary voltage supplies. The 5V supply will be used to power the microcontroller, pull-up its respective signals, and power the transceiver circuit and sensors. The 7.2V regulator will be used to power two H-Bridge circuits because the primary power supply is not always stable. It has the capability of exceeding the 7.2V rating and could possibly damage the H-Bridge circuits. The maximum power drawn from the supplies is approximately 122 mA. The primary supply chosen is well within specifications to supply this load.

Accelerometer

The accelerometer will provide the acceleration state of the vehicle. The acceleration data will be an input to the ATMega16 microcontroller. The microcontroller will in turn, process and calculate the velocity of the vehicle. This information will be used for controlling the speed of the vehicle. The current model provided by the Mechanical Engineering & Mechanics (MEM) Department is the ADXL105AQC made by Analog Devices. The advantages of this part are that it can measure both dynamic acceleration (for vibration) and static acceleration (for tilt) and is low cost. Appendix H contains additional information concerning this component.

Magnetometer

The magnetometer will provide direction orientation with respect to the earth's magnetic field. The MEM Department has provided the Honeywell Three-Axis Magnetoresistive Sensor HMC1023 to investigate its applicability for use in the vehicle. Please refer to Appendix I for additional information on this component. The three axis signals from magnetometer will produce differential voltages which will be fed into an analog-to digital converter. The converted digital signals will then be sent into the microcontroller for processing.

Camera Sensor

The camera sensor will capture the image of the vehicle's environment and will essentially be the "eyes" of the vehicle. The reason for implementing a camera sensor in this design is because it can be used for line-following and for obstacle detection. Instead of using two separate sensors such as an infrared LED sensor and sonar sensor to detect lines and obstacles, respectively, a single sensor can be used as a replacement. The initial goal of the camera sensor is to capture the image of a white background marked with a dark colored line. The objective will be to program the vehicle to track and to follow the colored line. As this technique is improved, additional functionality of the camera will be for simple obstacle recognition.

The specific camera sensor investigated in this design is the Logitech Quickcam Express Web camera (specifications in Appendix J). The reasons for this choice are that the camera is inexpensive and Logitech provides a software development kit which can be used to track color.

Program Software

Programming will play an important role in the design. In order for the sensors to work in conjunction with the ATMega16, the microcontroller will need to be programmed using an embedded C programming language. The advantage of using the ATMega16 is that there is a C compiler program (CodeVisionAVR) written specifically for the Atmel microcontroller. CodeVisionAVR, written by Pavel Haiduc of HP InfoTech S.R.L, is a completely integrated development environment (IDE) which allows for editing, compiling, part programming, and debugging to be performed from one personal computer (PC) Windows application [4]. CodeVisionAVR allows for smaller, more precise and efficient code which can utilize the many features of the Atmel microcontroller without waste [4].

The graphical user interface (GUI) is the display on the computer for which the user will see the data information from the accelerometer, magnetometer, and camera sensor. The GUI will be programmed using Microsoft Visual Basic (VB). VB was selected because it is relatively easy to learn and is very effective in GUI programming.

B. Analysis, Testing and Validation

Software packages such as PSpice can be used for circuit simulation prior to hardware implementation. It can be used to validate the functionality of the circuit design. All the circuit boards and wiring for the electrical components must be tested to make sure that they are working properly. One way to test this is to utilize a voltmeter to verify that there are no shorts in the circuit. In the programming / software aspects, CodeVisionAVR will be used to compile and debug microcontroller C code. The GUI will be debugged and compiled using Microsoft Visual Basic.

Data received from the vehicle sensors will be stored and analyzed by the microcontroller. The data received from the sensors will be analyzed and fed back for motor control and compensation. The sensor data will be sent back via RS232 serial cable to a vehicle guidance GUI. The image data from the camera sensor will be sent back via universal serial bus (USB) port. The VB program will process the incoming image data and feed back a compensated value to the microcontroller for motor input.

There is no need for special facilities, only a 15’ x 15’ room with a flat surface. Testing will include the vehicle’s ability to follow a straight line initially. A reference point will be placed in front of the rover to measure the deviation from the line path. By experimenting through trial and error, the control algorithm code will be calibrated until deviation is minimized. Once deviation is minimized to within ±25% then an acceptable solution to the problem is obtained. This concludes the validation process.

C. Further Research

Upon completion of the proposed method of solutions mentioned above, further research for the camera sensor will focus upon obstacle avoidance and target tracking specifically. If time permits, additional research into wireless capabilities for data transfer will be investigated.

D. Alternative Solutions

An alternative solution for the accelerometer is to implement a tachometer. A tachometer measures rotational speed and can be used to determine the revolutions per minute (RPM) of the motor. In order for this to work, the resolution of the motors (in terms of distance per revolution) will first need to be determined. Once this information is acquired, the distanced traveled can be calculated and hence the linear speed of the vehicle can be obtained.

In terms of direction, global positioning satellites (GPS) can be an alternate solution for direction orientation and position. However, the drawback to GPS is that it is difficult to use indoors because there is no clear line of sight to the satellites.

There are alternative methods that can be implemented for the vehicle to follow a line. In place of using a web camera sensor to track a line, a color sensor may also be used. A color sensor is designed specifically to measure color based upon a color model, which is most commonly the red, green, blue (RGB) model [5]. The color sensor can determine the RGB value by one of two methods: (1) reflecting all three colors off the colored surface and measuring the outcome (2) taking in the normal output and breaking it down into individual color components [5]. One particular model researched is the TAOS TCS230 Color Sensor kit. The advantage of color sensors is that it is ideal for use in line-following, but is limited to line-following and may not be effectively used for object detection.

In the case that the proposed camera sensor does not meet our design requirements, a customized line following circuit will be implemented. The circuit will consist of an array of five integrated circuits, each composed of a LED and an infrared detector. Compared to the Lynxmotion line following sensor, this circuit will increase the position resolution of the line. This could potentially eliminate the “jerky” motion of the vehicle.

III. Project Management Timeline

The goal of the project is to construct a working prototype vehicle with the three sensors: accelerometer, magnetometer, and camera by the end of April 2004. Appendix B presents the Gantt chart which plans out the overall breakdown of schedules for the length of the project. The project will involve major phases and milestones that will need to be accomplished (Appendix C). The team meets two times a week in four hour sessions. Weekly meeting logs are recorded to document each step and phase of the design.

The project team consists of members from the following academic disciplines:

(2) Mechanical Engineering

(1) Electrical Engineering

(1) Computer Engineering

The team members have combined background in controls theory, circuit design, microcontroller theory, and C++ programming. Two team members are currently taking a micro-based controls system course which directly involves the study of the AVR microcontroller and its applications. Two team members have background in C++ programming and VB programming. These combinations of skill sets will play an important role in the design throughout the year.

Each member of the team will be responsible for various tasks, but all the team members are encouraged to learn and ask questions on all the aspects of the project. The design team consists of four engineering students, one of which is the team leader. The team leader is responsible for communication and organization between all the engineers. This includes sending weekly emails about goals that need to be achieved, setting up weekly meetings to achieve those goals, and keeping weekly meeting minutes of work done. These communication tasks are paramount for good team work and will aid in the progress of the project.

Tasks of the project include, but are not limited to designing the hardware for the vehicle, building the circuits for all the sensors, programming the ATMega16 microcontroller using CodeVisionAVR for the sensors, and programming in VB for the camera sensor. These tasks will be evenly distributed to each member of the team including the team leader. The goal or focus is to promote a pleasant work environment so that all team members will be motivated to learn rather than just work.

IV. Economic Analysis

The MEM Department will provide the majority of the supplies and computing resources required for the project. The work will be held in the Alumni Engineering Lab (AEL) room 174 located in the Main Building at Drexel University. The MEM Department has currently provided the accelerometer sensor, magnetometer sensor, Logitech QuickCam camera sensor, H-bridge, vehicle chassis (including motors and rechargeable battery), sockets, and electrical components. The out-of-pocket expense consists of the purchase of three ATMEL STK500 Microcontroller kits and one set of LED (IR & Photosensors) for a total of $252.00. The estimated budget for the prototype of the vehicle including the basic rover, microcontroller, accelerometer, magnetometer, camera and all circuits required is approximately $541.36 (Appendix D).

The overall industry budget consists of accumulated engineering-hours, laboratory tools, office supplies and software license purchases. The budget factors eight hours per week for each engineer working for a period of 38 weeks (304 total hours per engineer). The industry budget totals an estimated cost of $96,202.72 (Appendix D).

V. Societal and Environmental Impact Analysis

The role of an engineer is to think of ways to help society with their designs, whether it is making difficult tasks easier or saving lives from harms way. The role of this vehicle is intended for military purposes. For applications in the real world, the semi-autonomous vehicle can follow a soldier in combat to a final destination. The vehicle can assist with carrying supplies so that the soldier will not have to expend energy on carrying bulky loads. Another application is to have these vehicles dropped behind enemy lines to survey the land. Information such as enemy position and building structures can be captured by the vehicle and transmitted to a safe location for analysis. This will give the soldiers an idea of what the environment is like without putting their lives at risk. Losing expendable vehicles during combat is better than losing a priceless human life that in itself would justify the need of such a vehicle.

In terms of environment analysis, the proposed vehicle will run on rechargeable battery power. The components used are simple electronic circuit boards, wires, microchips / microcontrollers, and do not produce any harmful waste to the environment. Proper disposal measures will have to be taken in order to appropriately dispose of the battery when it is at the end of its usable lifecycle.

VI. Summary and Conclusion

In order to reduce casualties of soldiers there is a need for semi-autonomous vehicles to perform scouting tasks that may be too dangerous for them on the battlefield. The target and main objective of this project is to produce a working prototype vehicle that will have the capability to visually follow a line via the camera sensor. From a central computer, the VB program will process the images taken from the camera sensor. The program will relay appropriate instructions to the vehicle to follow the line path. Position and velocity will also be recorded by this program via the magnetometer and accelerometer sensors. These three functionalities will be controlled and processed by the ATMega16 microcontroller. In the design process, necessary electrical and controls equipment need to be designed and integrated into the vehicle. Once the validation process is completed, testing will be performed. With this functionality, the vehicle can be used for assisting soldiers and scouting. At the conclusion of the project a working prototype of the semi-autonomous vehicle will be delivered.

VI. References

Works Cited

[1] Carnegie Mellon University. The CMUcam Vision Sensor. 14 November 2003. [Online] Available: http://www-2.cs.cmu.edu/~cmucam/index.html

[2] Kehtarnavaz, N., Griswold, N.C. , Lee, J.S., 1991, "Visual control of an autonomous vehicle (BART)-the vehicle-following problem," IEEE Transactions on Vehicular Technology, Vol. 40, Issue 3, pp. 654-662.

[3] AVR STK500 User Guide, Atmel, version 1925C, 2003.

[4] Barnett R., Cox S., and O'Cull L., 2003, *Embedded C Programming and the Atmel AVR*. Thomson Delmar Learning, Canada.

[5] Motion Control Sensors. The Color Sensor. 14 November 2003. [Online] Available: http://www.theproductfinder.com/sensors/colsen.htm

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McCoy, M., Taylor, C., 2001, "Design and Fabrication of Distributed Bragg Reflectors for use in RCLEDs and VCSELs", University of Illinois at Urbana-Champaign.

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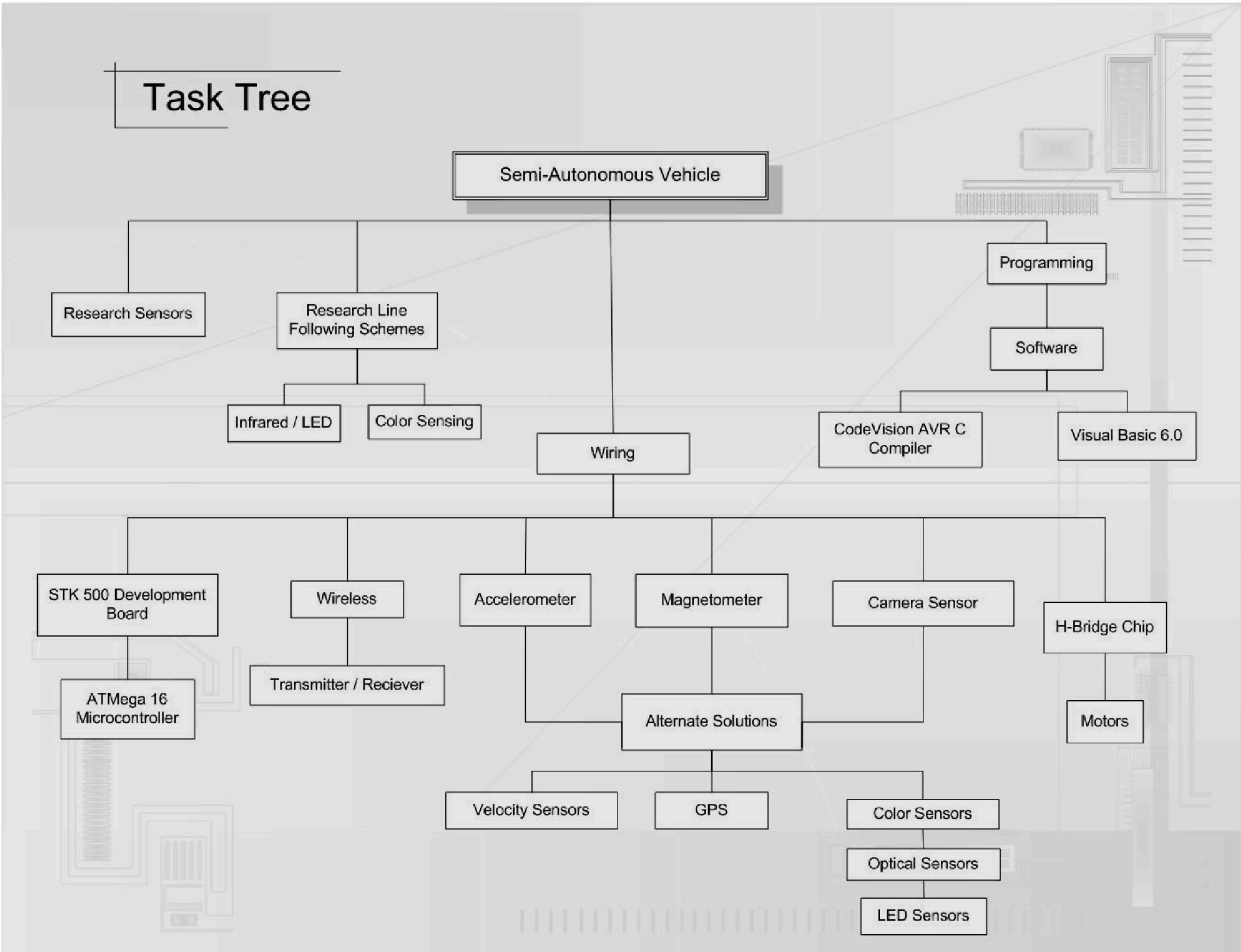
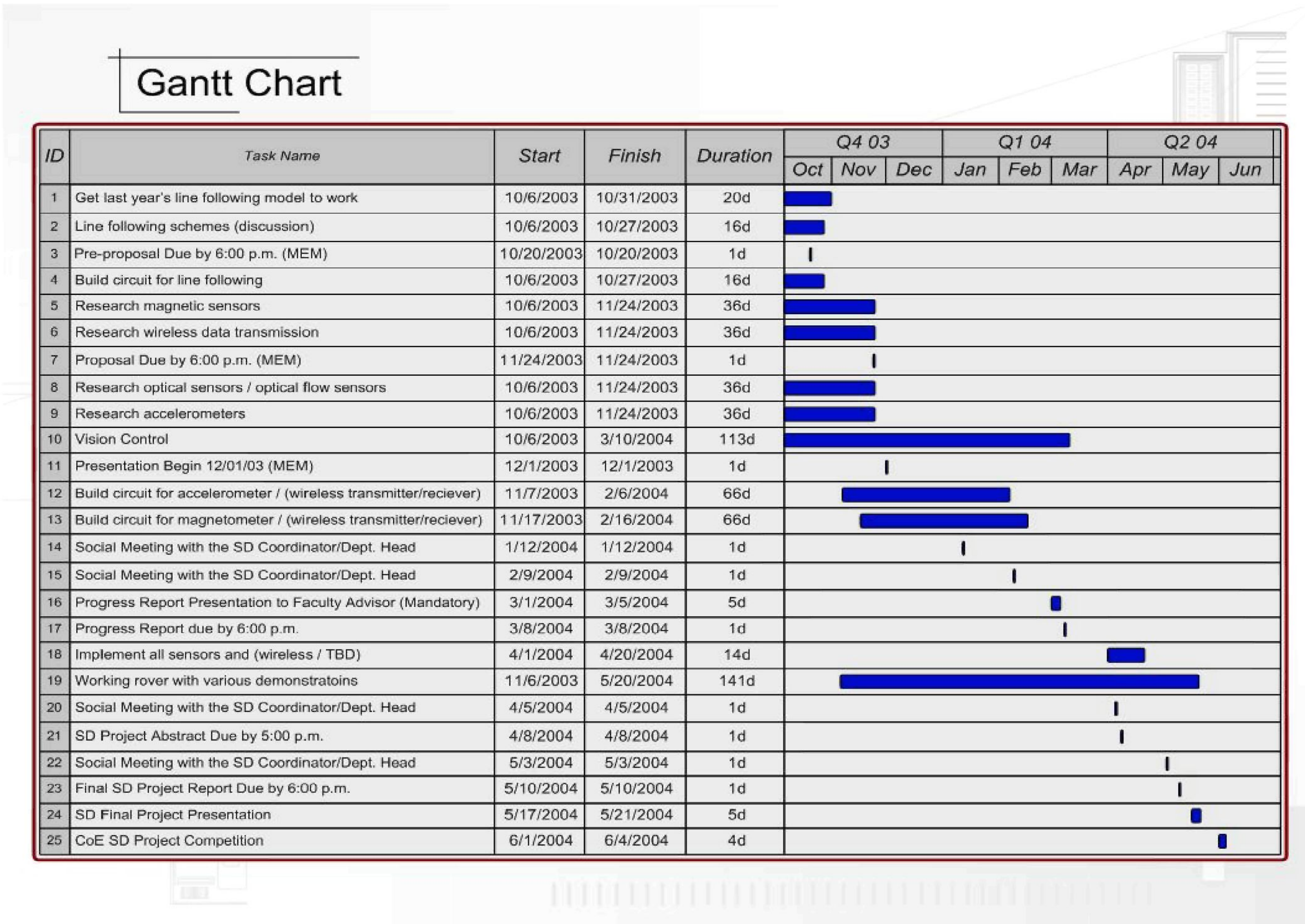
VII. Appendices

Appendix A: Task Tree



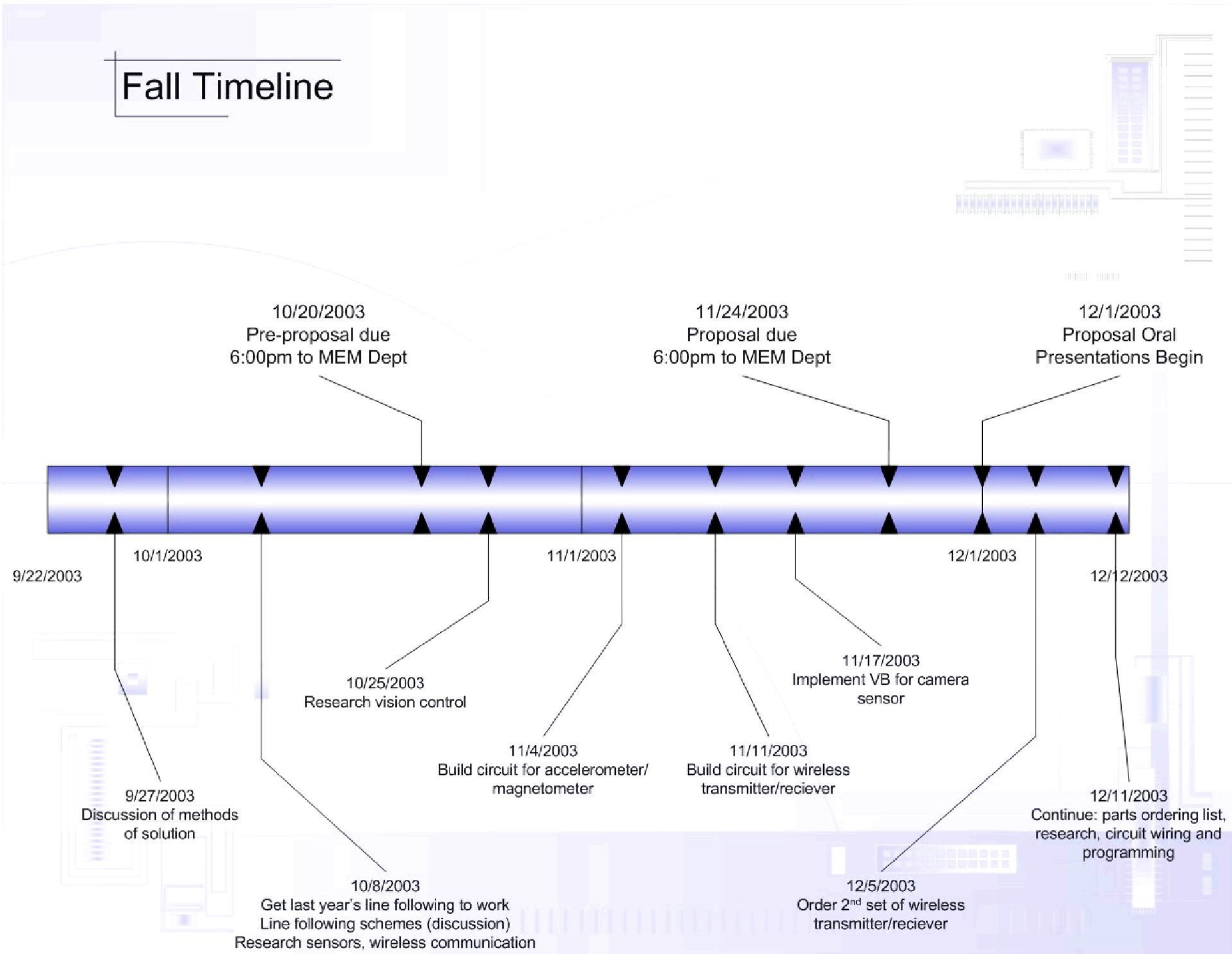
Appendix B: Gantt Chart



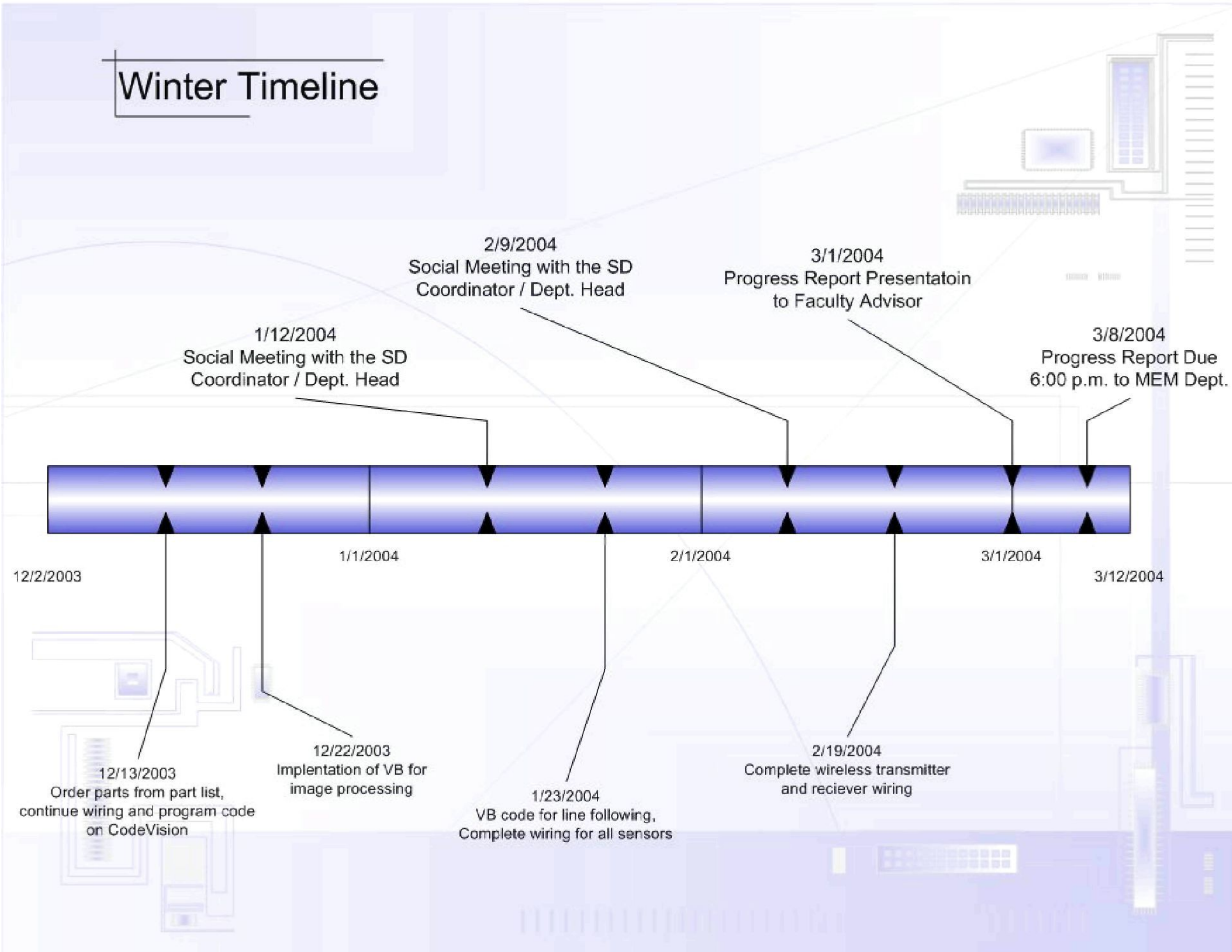
Gantt Chart

ID	Task Name	Start	Finish	Duration
1	Get last year's line following model to work	10/6/2003	10/31/2003	20d
2	Line following schemes (discussion)	10/6/2003	10/27/2003	16d
3	Pre-proposal Due by 6:00 p.m. (MEM)	10/20/2003	10/20/2003	1d
4	Build circuit for line following	10/6/2003	10/27/2003	16d
5	Research magnetic sensors	10/6/2003	11/24/2003	36d
6	Research wireless data transmission	10/6/2003	11/24/2003	36d
7	Proposal Due by 6:00 p.m. (MEM)	11/24/2003	11/24/2003	1d
8	Research optical sensors / optical flow sensors	10/6/2003	11/24/2003	36d
9	Research accelerometers	10/6/2003	11/24/2003	36d
10	Vision Control	10/6/2003	3/10/2004	113d
11	Presentation Begin 12/01/03 (MEM)	12/1/2003	12/1/2003	1d
12	Build circuit for accelerometer / (wireless transmitter/reciever)	11/7/2003	2/6/2004	66d
13	Build circuit for magnetometer / (wireless transmitter/reciever)	11/17/2003	2/16/2004	66d
14	Social Meeting with the SD Coordinator/Dept. Head	1/12/2004	1/12/2004	1d
15	Social Meeting with the SD Coordinator/Dept. Head	2/9/2004	2/9/2004	1d
16	Progress Report Presentation to Faculty Advisor (Mandatory)	3/1/2004	3/5/2004	5d
17	Progress Report due by 6:00 p.m.	3/8/2004	3/8/2004	1d
18	Implement all sensors and (wireless / TBD)	4/1/2004	4/20/2004	14d
19	Working rover with various demonstratoins	11/6/2003	5/20/2004	141d
20	Social Meeting with the SD Coordinator/Dept. Head	4/5/2004	4/5/2004	1d
21	SD Project Abstract Due by 5:00 p.m.	4/8/2004	4/8/2004	1d
22	Social Meeting with the SD Coordinator/Dept. Head	5/3/2004	5/3/2004	1d
23	Final SD Project Report Due by 6:00 p.m.	5/10/2004	5/10/2004	1d
24	SD Final Project Presentation	5/17/2004	5/21/2004	5d
25	CoE SD Project Competition	6/1/2004	6/4/2004	4d

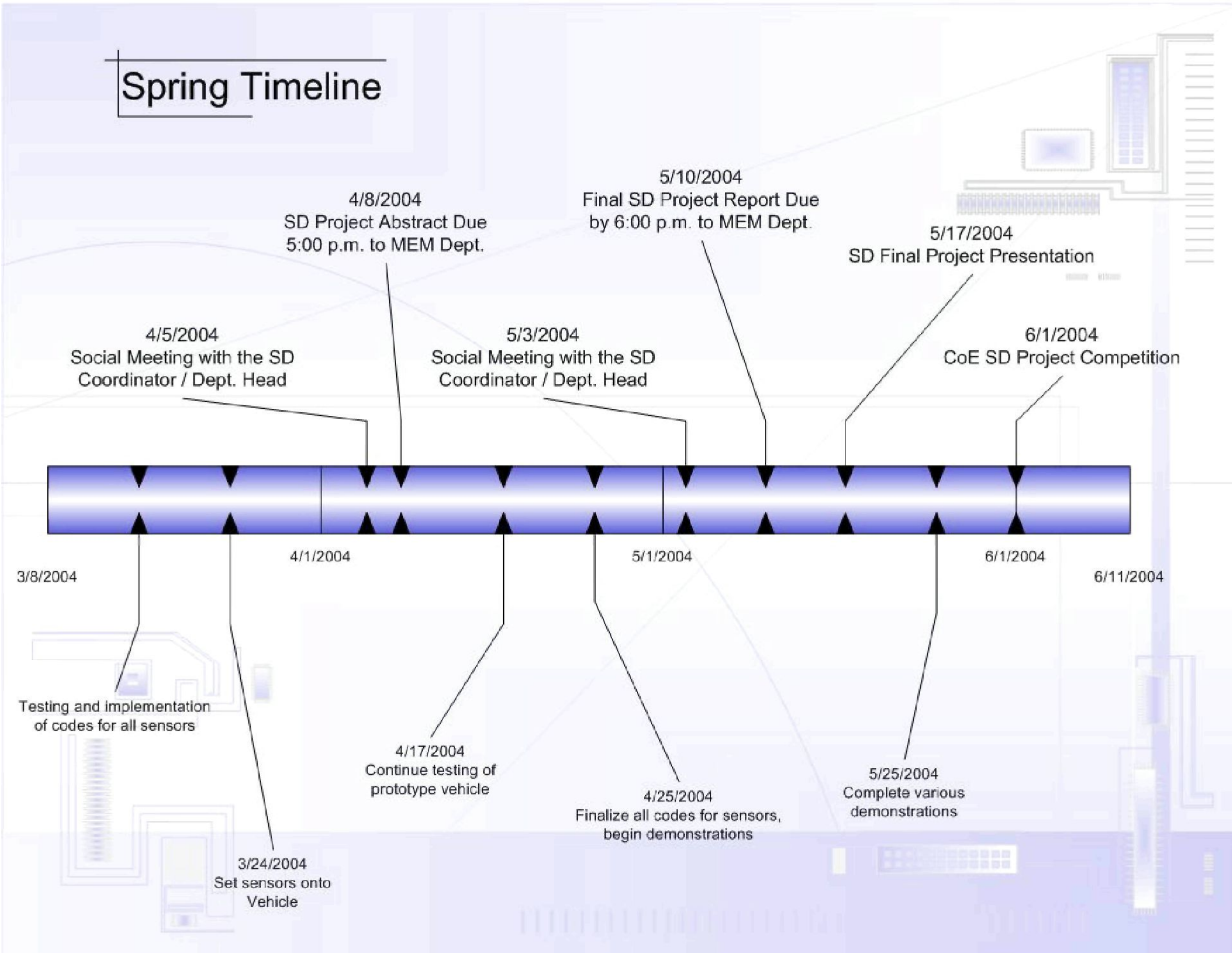
Appendix C: Timeline (Fall)



Appendix C: Timeline (Winter)



Appendix C: Timeline (Spring)



Appendix D: Economic Analysis

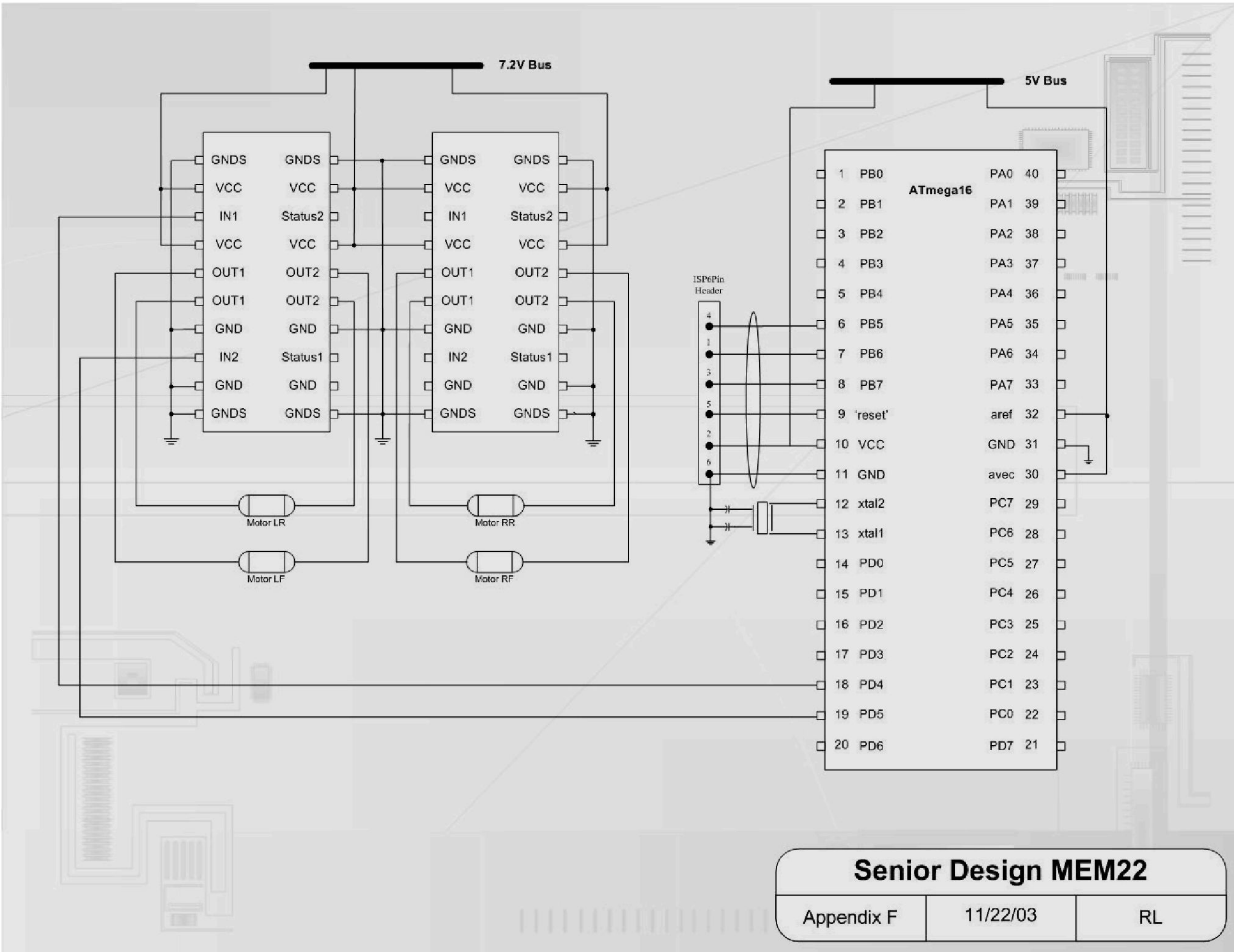
Budget for Building Concept-Demonstration Prototype				
Description	**Qty**	**Unit**	**Cost Per**	**Actual Cost**
Lynxmotion 4WD2 Robot Basic Kit	1	Each	$ 211.80	$ 211.80
ATMEL STK500 Microcontroller Kit	1	Each	$ 80.00	$ 80.00
Accelerometer Sensor (ADXL105QC)	1	Each	$ 23.94	$ 23.94
Magnetometer Sensor (HMC1023)	1	Each	$ 100.00	$ 100.00
Logitech QuickCam Express USB PC Video Camera	1	Each	$ 17.00	$ 17.00
H-Bridges	1	Each	$ 20.00	$ 20.00
Connector, Pin, Fem	1	Pack	$ 11.05	$ 11.05
Radio Shack - Sockets, Wires, Capacitors, Resistors	1	Pack	$ 57.57	$ 57.57
Voltage Regulators	1	Each	$ 20.00	$ 20.00
Total				**$ 541.36**

Budget for Engineering Development Project					
Description	**Qty**	**Unit**	**Cost Per**	**Actual Cost**	**Out-of-Pocket**
Lynxmotion 4WD2 Robot Basic Kit	1	Each	$ 211.80	$ 211.80	$ 0.00
ATMEL STK500 Microcontroller Kit	3	Each	$ 80.00	$ 240.00	$ 240.00
Accelerometer Sensor (ADXL105QC)	1	Each	$ 23.94	$ 23.94	$ 0.00
Magnetometer Sensor (HMC1023)	1	Each	$ 100.00	$ 100.00	$ 0.00
Logitech QuickCam Express USB PC Video Camera	1	Each	$ 17.00	$ 17.00	$ 0.00
LED (IR & Phototransistor)	1	Lot	$ 12.00	$ 12.00	$ 12.00
H-Bridges	1	Each	$ 20.00	$ 20.00	$ 0.00
Transmitter (TXM-433-LC)	1	Each	$ 6.90	$ 6.90	$ 0.00
Receiver (RXM-433-LC-S)	1	Each	$ 13.79	$ 13.79	$ 0.00
Antennas (ANT-433-CW-HD)	1	Each	$ 15.22	$ 15.22	$ 0.00
Connector, Pin, Fem	1	Pack	$ 11.05	$ 11.05	$ 0.00
Radio Shack - Sockets, Wires, Capacitors, Resistors	1	Pack	$ 57.57	$ 57.57	$ 0.00
Voltage Regulators	1	Each	$ 20.00	$ 20.00	$ 0.00
Wire Wrapper	1	Each	$ 20.05	$ 20.05	$ 0.00
Laboratory Tools	1	Lot	$ 200.00	$ 200.00	$ 0.00
Office Supplies	1	Lot	$ 200.00	$ 200.00	$ 0.00
Total				**$ 1,169.32**	**$ 252.00**

Industry Budget			
	Cost per Unit	**Total Units**	**Total Cost**
Employees			
Mechanical Engineer	$30.00 / hour	304 hours	$ 9,120.00
Electrical Engineer	$30.00 / hour	304 hours	$ 9,120.00
Computer Engineer	$30.00 / hour	304 hours	$ 9,120.00
Project Manager	$50.00 / hour	304 hours	$ 15,200.00
Software Licensing	$5,000.00	1	$ 5,000.00
Materials	$541.36	1	$ 541.36
Total Labor, Software, Materials			$ 48,101.36
Overhead @ 100%			$ 48,101.36
Total Industrial Budget			**$ 96,202.72**

Appendix E:
Lynxmotion 4WD2 Robot Basic Kit

Appendix F:
ATMega16 & Components Schematic



Appendix G:
Atmel ATMega16 Microcontroller Datasheet

Features

- High-performance, Low-power AVR® 8-bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single-clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle Multiplier
- Nonvolatile Program and Data Memories
  - 16K Bytes of In-System Self-Programmable Flash
    Endurance: 10,000 Write/Erase Cycles
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - 512 Bytes EEPROM
    Endurance: 100,000 Write/Erase Cycles
  - 1K Byte Internal SRAM
  - Programming Lock for Software Security
- JTAG (IEEE std. 1149.1 Compliant) Interface
  - Boundary-scan Capabilities According to the JTAG Standard
  - Extensive On-chip Debug Support
  - Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Four PWM Channels
  - 8-channel, 10-bit ADC
    8 Single-ended Channels
    7 Differential Channels in TQFP Package Only
    2 Differential Channels with Programmable Gain at 1x, 10x, or 200x
  - Byte-oriented Two-wire Serial Interface
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby and Extended Standby
- I/O and Packages
  - 32 Programmable I/O Lines
  - 40-pin PDIP, 44-lead TQFP, and 44-pad MLF
- Operating Voltages
  - 2.7 - 5.5V for ATmega16L
  - 4.5 - 5.5V for ATmega16
- Speed Grades
  - 0 - 8 MHz for ATmega16L
  - 0 - 16 MHz for ATmega16
- Power Consumption @ 1 MHz, 3V, and 25°C for ATmega16L
  - Active: 1.1 mA
  - Idle Mode: 0.35 mA
  - Power-down Mode: < 1 µA

8-bit AVR® Microcontroller with 16K Bytes In-System Programmable Flash

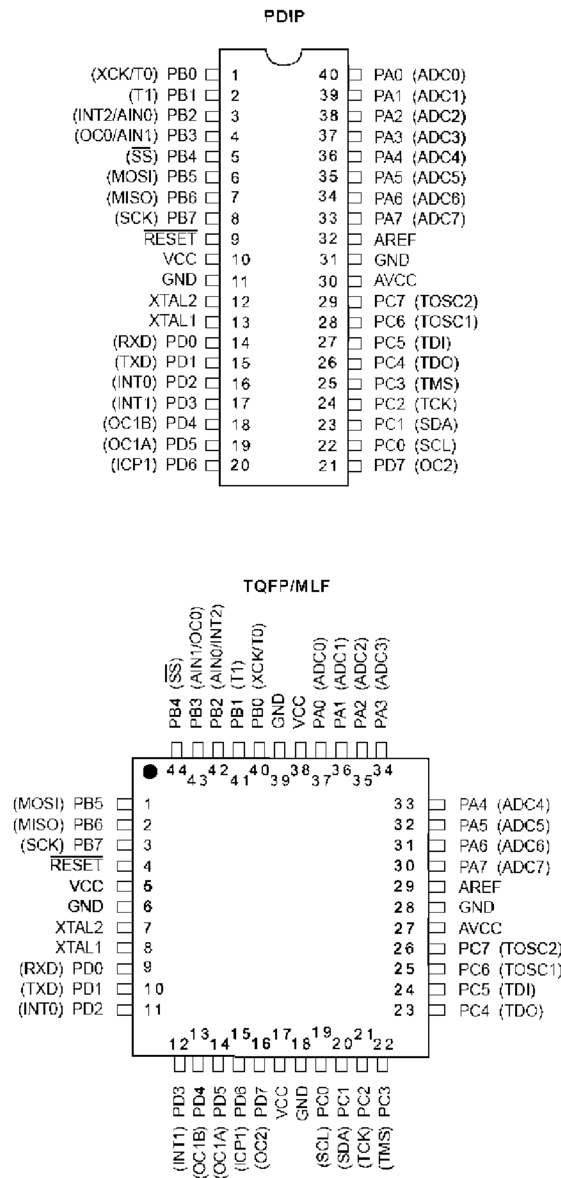
ATmega16
ATmega16L

2466G–AVR–10/03

Appendix G:
Atmel ATMega16 Microcontroller Datasheet

Pin Configurations

Figure 1. Pinouts ATmega16



Disclaimer

Typical values contained in this datasheet are based on simulations and characterization of other AVR microcontrollers manufactured on the same process technology. Min and Max values will be available after the device is characterized.

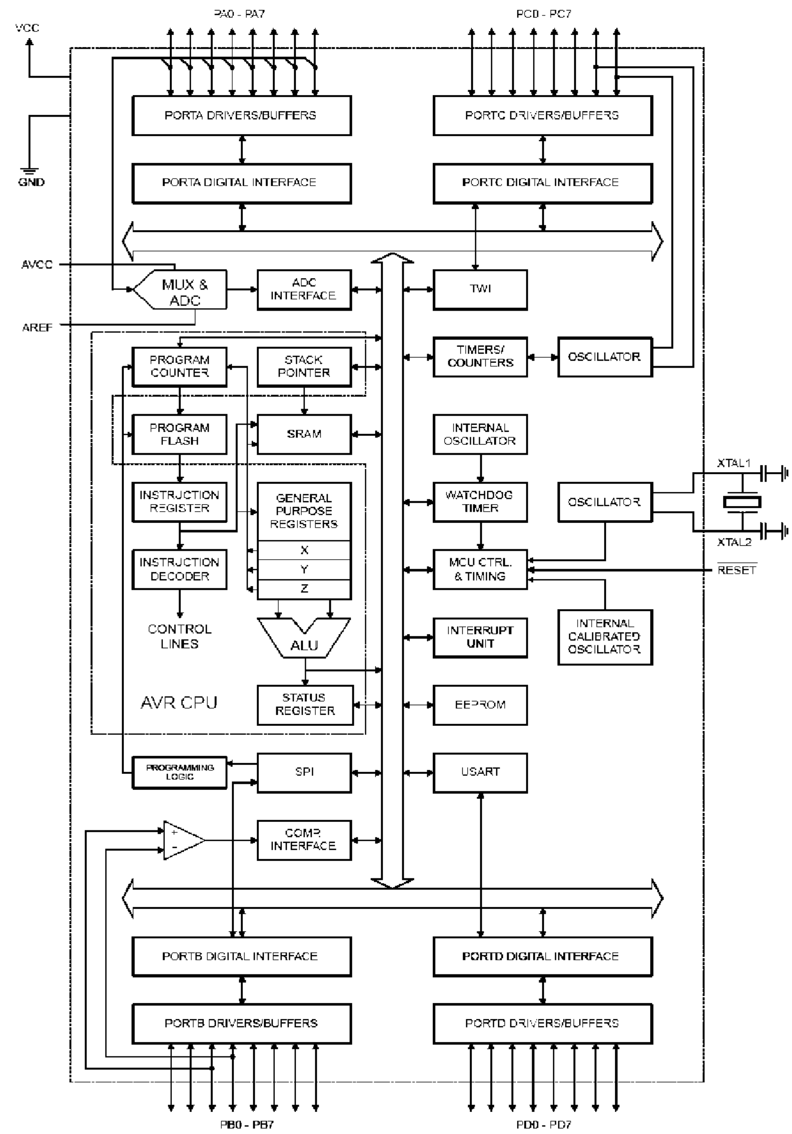
Appendix G:
Atmel ATMega16 Microcontroller Datasheet

Overview

The ATmega16 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega16 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

Block Diagram

Figure 2. Block Diagram



Appendix G:
Atmel ATMega16 Microcontroller Datasheet

The AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The ATmega16 provides the following features: 16K bytes of In-System Programmable Flash Program memory with Read-While-Write capabilities, 512 bytes EEPROM, 1K byte SRAM, 32 general purpose I/O lines, 32 general purpose working registers, a JTAG interface for Boundary-scan, On-chip Debugging support and programming, three flexible Timer/Counters with compare modes, Internal and External Interrupts, a serial programmable USART, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain (TQFP package only), a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and six software selectable power saving modes. The Idle mode stops the CPU while allowing the USART, Two-wire interface, A/D Converter, SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next External Interrupt or Hardware Reset. In Power-save mode, the Asynchronous Timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except Asynchronous Timer and ADC, to minimize switching noise during ADC conversions. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption. In Extended Standby mode, both the main Oscillator and the Asynchronous Timer continue to run.

The device is manufactured using Atmel's high density nonvolatile memory technology. The On-chip ISP Flash allows the program memory to be reprogrammed in-system through an SPI serial interface, by a conventional nonvolatile memory programmer, or by an On-chip Boot program running on the AVR core. The boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash section will continue to run while the Application Flash section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega16 is a powerful microcontroller that provides a highly-flexible and cost-effective solution to many embedded control applications.

The ATmega16 AVR is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, in-circuit emulators, and evaluation kits.

Pin Descriptions

VCC

Digital supply voltage.

GND

Ground.

Port A (PA7..PA0)

Port A serves as the analog inputs to the A/D Converter.

Port A also serves as an 8-bit bi-directional I/O port, if the A/D Converter is not used. Port pins can provide internal pull-up resistors (selected for each bit). The Port A output buffers have symmetrical drive characteristics with both high sink and source capability. When pins PA0 to PA7 are used as inputs and are externally pulled low, they will source current if the internal pull-up resistors are activated. The Port A pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Appendix G: Atmel ATMega16 Microcontroller Datasheet

Port B (PB7..PB0)

Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port B also serves the functions of various special features of the ATmega16 as listed on page 56.

Port C (PC7..PC0)

Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port C output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running. If the JTAG interface is enabled, the pull-up resistors on pins PC5(TDI), PC3(TMS) and PC2(TCK) will be activated even if a reset occurs.

Port C also serves the functions of the JTAG interface and other special features of the ATmega16 as listed on page 59.

Port D (PD7..PD0)

Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port D also serves the functions of various special features of the ATmega16 as listed on page 61.

$\overline{\text{RESET}}$

Reset Input. A low level on this pin for longer than the minimum pulse length will generate a reset, even if the clock is not running. The minimum pulse length is given in Table 15 on page 36. Shorter pulses are not guaranteed to generate a reset.

XTAL1

Input to the inverting Oscillator amplifier and input to the internal clock operating circuit.

XTAL2

Output from the inverting Oscillator amplifier.

AVCC

AVCC is the supply voltage pin for Port A and the A/D Converter. It should be externally connected to V_{CC}, even if the ADC is not used. If the ADC is used, it should be connected to V_{CC} through a low-pass filter.

AREF

AREF is the analog reference pin for the A/D Converter.

About Code Examples

This documentation contains simple code examples that briefly show how to use various parts of the device. These code examples assume that the part specific header file is included before compilation. Be aware that not all C Compiler vendors include bit definitions in the header files and interrupt handling in C is compiler dependent. Please confirm with the C Compiler documentation for more details.

Appendix H:
Analog Devices ADXL105 Datasheet

ANALOG DEVICES

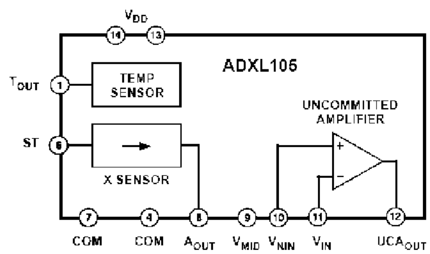
High Accuracy ±1 *g* to ±5 *g* Single Axis *i*MEMS® Accelerometer with Analog Input

ADXL105*

FEATURES
Monolithic IC Chip
2 m*g* Resolution
10 kHz Bandwidth
Flat Amplitude Response (±1%) to 5 kHz
Low Bias and Sensitivity Drift
Low Power 2 mA
Output Ratiometric to Supply
User Scalable *g* Range
On-Board Temperature Sensor
Uncommitted Amplifier
Surface Mount Package
+2.7 V to +5.25 V Single Supply Operation
1000 *g* Shock Survival

APPLICATIONS
Automotive
Accurate Tilt Sensing with Fast Response
Machine Health and Vibration Measurement
Affordable Inertial Sensing of Velocity and Position
Seismic Sensing
Rotational Acceleration

FUNCTIONAL BLOCK DIAGRAM



GENERAL DESCRIPTION

The ADXL105 is a high performance, high accuracy and complete single-axis acceleration measurement system on a single monolithic IC. The ADXL105 offers significantly increased bandwidth and reduced noise versus previously available micromachined devices. The ADXL105 measures acceleration with a full-scale range up to ±5 *g* and produces an analog voltage output. Typical noise floor is 225 $\mu g\sqrt{Hz}$ allowing signals below 2 m*g* to be resolved. A 10 kHz wide frequency response enables vibration measurement applications. The product exhibits significant reduction in offset and sensitivity drift over temperature compared to the ADXL05.

The ADXL105 can measure both dynamic accelerations, (typical of vibration) or static accelerations (such as inertial force, gravity or tilt).

Output scale factors from 250 mV/*g* to 1.5 V/*g* are set using the on-board uncommitted amplifier and external resistors. The device features an on-board temperature sensor with an output of 8 mV/°C for optional temperature compensation of offset vs. temperature for high accuracy application.

The ADXL105 is available in a hermetic 14-lead surface mount Cerpak with versions specified for the 0°C to +70°C, and –40°C to +85°C temperature ranges.

*Patent Pending.
*i*MEMS is a registered trademark of Analog Devices, Inc.

REV. A

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781/329-4700 World Wide Web Site: http://www.analog.com
Fax: 781/326-8703

Appendix H:
Analog Devices ADXL105 Datasheet

ADXL105–SPECIFICATIONS ($T_A = T_{MIN}$ to T_{MAX}, $T_A = +25°C$ for J Grade Only, $V_S = +5$ V, @ Acceleration = 0 *g*, unless otherwise noted)

Parameter	Conditions	ADXL105J/A Min	Typ	Max	Units
SENSOR INPUT					
Measurement Range[1]		±5	±7		*g*
Nonlinearity	Best Fit Straight Line		0.2		% of FS
Alignment Error[2]			±1		Degrees
Cross Axis Sensitivity[3]	Z Axis, @ +25°C		±1	±5	%
SENSITIVITY[4] (Ratiometric)	At A_{OUT}				
Initial		225	250	275	mV/*g*
	V_S = 2.7 V	80	105	120	mV/*g*
vs. Temperature[5, 6]			±0.5		%
ZERO *g* BIAS LEVEL[5] (Ratiometric)	At A_{OUT}				
Zero *g* Offset Error	From +2.5 V Nominal	–625		+625	mV
vs. Supply		–20		+20	mV/V_{DD}/V
vs. Temperature[5, 7]			50		mV
NOISE PERFORMANCE					
Voltage Density[7]	@ +25°C		225	325	$\mu g/\sqrt{Hz}$
Noise in 100 Hz Bandwidth			2.25		mg rms
FREQUENCY RESPONSE					
3 dB Bandwidth		10	12		kHz
Sensor Resonant Frequency		13	18		kHz
TEMP SENSOR[4] (Ratiometric)					
Output Error at +25°C	From +2.5 V Nominal	–100		+100	mV
Nominal Scale Factor			8		mV/°C
Output Impedance			10		kΩ
V_{MID}[4] (Ratiometric)					
Output Error	From +2.5 V Nominal	–15		+15	mV
Output Impedance			10		kΩ
SELF-TEST (Proportional to V_{DD})					
Voltage Delta at A_{OUT}	Self-Test "0" to "1"	100		500	mV
Input Impedance[8]		30	50		kΩ
A_{OUT}					
Output Drive	I = ±50 µA	0.50		V_S – 0.5	V
Capacitive Load Drive		1000			pF
UNCOMMITTED AMPLIFIER					
Initial Offset		–25		+25	mV
Initial Offset vs. Temperature			5		µV/°C
Common-Mode Range		1.0		4.0	V
Input Bias Current[9]			25		nA
Open Loop Gain			100		V/mV
Output Drive	I = ±100 µA	0.25		V_S – 0.25	V
Capacitive Load Drive		1000			pF
POWER SUPPLY					
Operating Voltage Range		2.70		5.25	V
Quiescent Supply Current	At 5.0 V		1.9	2.6	mA
	At 2.7 V		1.3	2.0	mA
Turn-On Time			700		µs
TEMPERATURE RANGE					
Operating Range J		0		+70	°C
Specified Performance A		–40		+85	°C

NOTES

[1]Guaranteed by tests of zero *g* bias, sensitivity and output swing.
[2]Alignment of the X axis is with respect to the long edge of the bottom half of the Cerpak package.
[3]Cross axis sensitivity is measured with an applied acceleration in the Z axis of the device.
[4]This parameter is ratiometric to the supply voltage V_{DD}. Specification is shown with a 5.0 V V_{DD}. To calculate approximate values at another V_{DD}, multiply the specification by V_{DD}/5 V.
[5]Specification refers to the maximum change in parameter from its initial value at +25°C to its worst case value at T_{MIN} to T_{MAX}.
[6]See Figure 3.
[7]See Figure 2.
[8]CMOS and TTL Compatible.
[9]UCA input bias current is tested at final test.

All min and max specifications are guaranteed. Typical specifications are not tested or guaranteed.
Specifications subject to change without notice.

Appendix H:
Analog Devices ADXL105 Datasheet

ABSOLUTE MAXIMUM RATINGS*

Acceleration (Any Axis, Unpowered for 0.5 ms) . . . . . . 1000 *g*
Acceleration (Any Axis, Powered for 0.5 ms) . . . . 500 *g*
$+V_S$ . . . . –0.3 V to +7.0 V
Output Short Circuit Duration
(Any Pin to Common) . . . . Indefinite
Operating Temperature . . . . –55°C to +125°C
Storage Temperature . . . . –65°C to +150°C

*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Package Characteristics

Package	θ_{JA}	θ_{JC}	Device Weight
14-Lead Cerpak	110°C/W	30°C/W	<2 Grams

ORDERING GUIDE

Model	Temperature Range	Package Option
ADXL105JQC	0°C to +70°C	QC-14
ADXL105AQC	–40°C to +85°C	QC-14

CAUTION

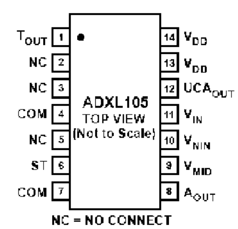
ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the ADXL105 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

Drops onto hard surfaces can cause shocks of greater than 1000 *g* and exceed the absolute maximum rating of the device. Care should be exercised in handling to avoid damage.

PIN FUNCTION DESCRIPTIONS

Pin No.	Name	Description
1	T_{OUT}	Temperature Sensor Output
2, 3, 5	NC	No Connect
4	COM	Common
6	ST	Self-Test
7	COM	Common (Substrate)
8	A_{OUT}	Accelerometer Output
9	V_{MID}	$V_{DD}/2$ Reference Voltage
10	V_{NIN}	Uncommitted Amp Noninverting Input
11	V_{IN}	Uncommitted Amp Inverting Input
12	UCA_{OUT}	Uncommitted Amp Output
13, 14	V_{DD}	Power Supply Voltage

PIN CONFIGURATION



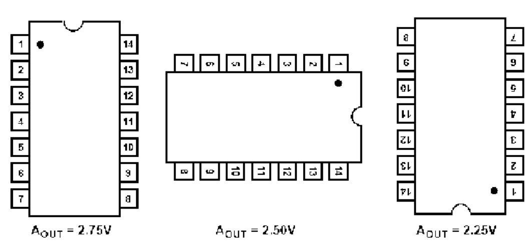


Figure 1. ADXL105 Response Due to Gravity

Appendix I:
Honeywell HMC1023 Three-Axis Magnetoresistive Sensor Datasheet

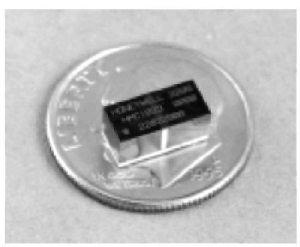
Honeywell

SENSOR PRODUCTS
Advance Information

Three-Axis Magnetoresistive Sensor
HMC1023

APPLICATIONS
- Compassing
- Navigation Systems
- Attitude Reference
- Virtual Reality
- Traffic Detection
- Proximity Detection
- Medical Devices

Not actual size



Configured as three magnetoresistive sensors in x, y and z orientation, these highly sensitive sensors convert all three magnetic field axes to a differential output voltage. This new addition to our line of magnetoresistive sensors is smaller, uses less power and is ideal for applications that require orthogonal three-axis sensing.

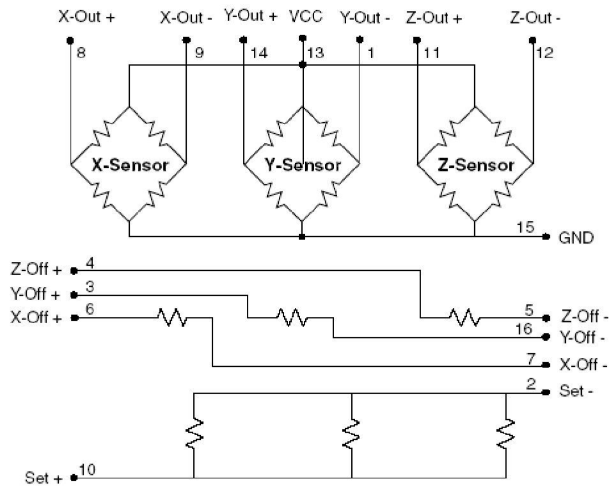
FEATURES AND BENEFITS

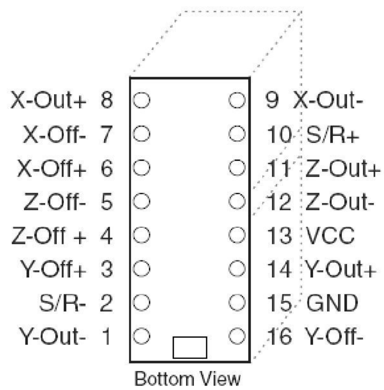
Wide Field Range	Field range of ±6 gauss, (earth's field = 0.5 gauss) while maintaining high sensitivity with a minimal detectable field down to 85 μgauss.
Small Package	Designed to work as a single stand alone three-axis (x,y,z) magnetoresistive sensing system. Custom Ball Grid Array (BGA), 1mm pitch, 16-pin miniature package provides a small footprint and accurate sensor placement for orthogonal three-axis sensing applications.
Solid State	This small device reduces board assembly costs, improves reliability and ruggedness compared to mechanical fluxgates.
Low Power	The patented on-chip set/reset and offset straps have been improved and now require 50% less power to drive the set-reset and offset functions. This sensor can be operated with a 3 to 25 volt power supply, lowering power consumption and reducing support circuitry.
Cost Effective	The sensors were specifically designed to be affordable for high volume OEM applications.

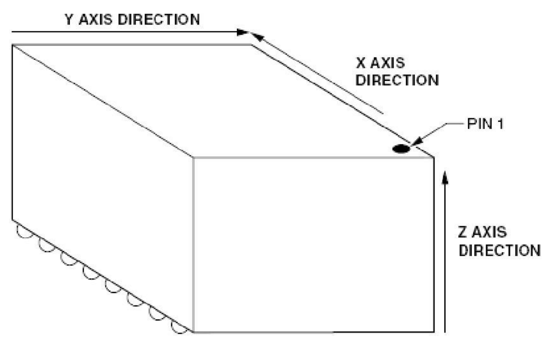
Appendix I:
Honeywell HMC1023 Three-Axis Magnetoresistive Sensor Datasheet

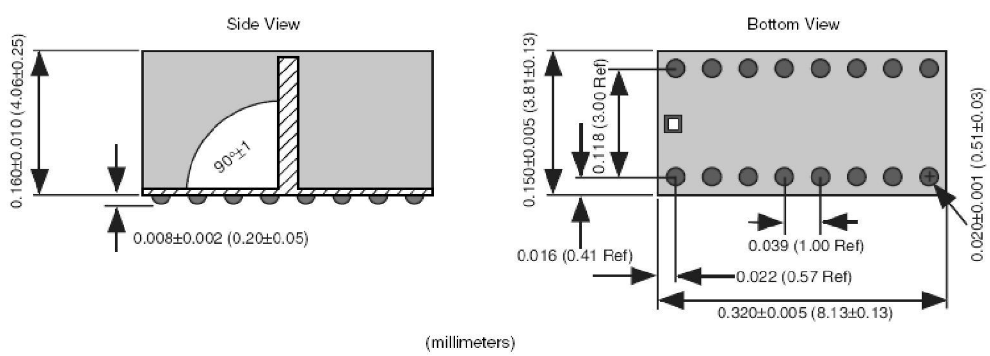
HMC1023

MR SENSOR CIRCUIT / PINOUT SPECIFICATIONS





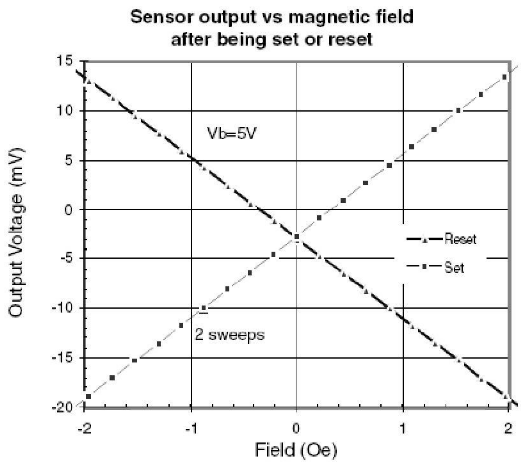


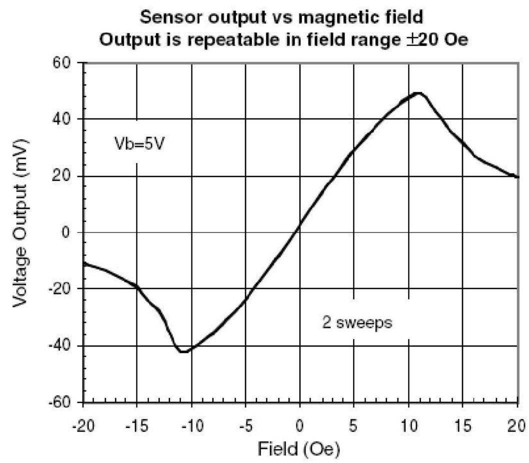


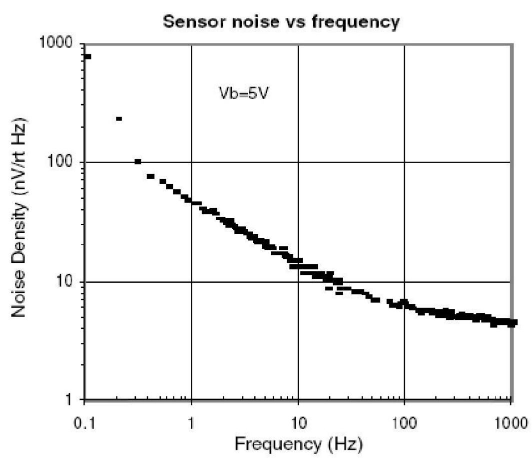
2

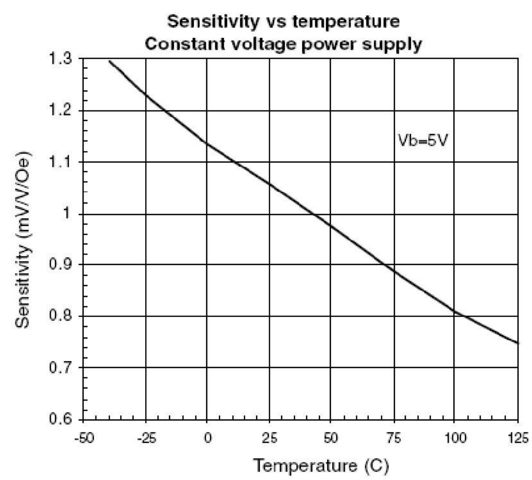
Appendix I:
Honeywell HMC1023 Three-Axis Magnetoresistive Sensor Datasheet

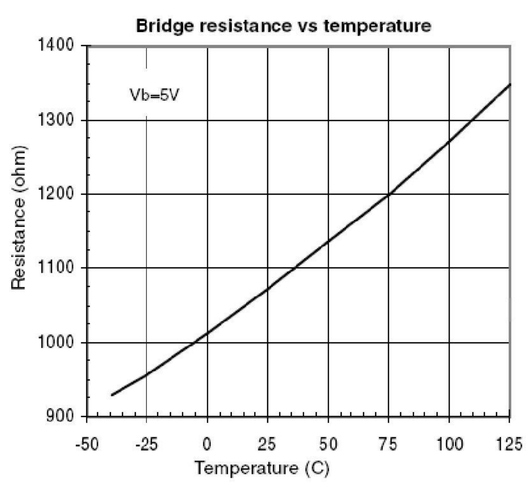
KEY PERFORMANCE DATA

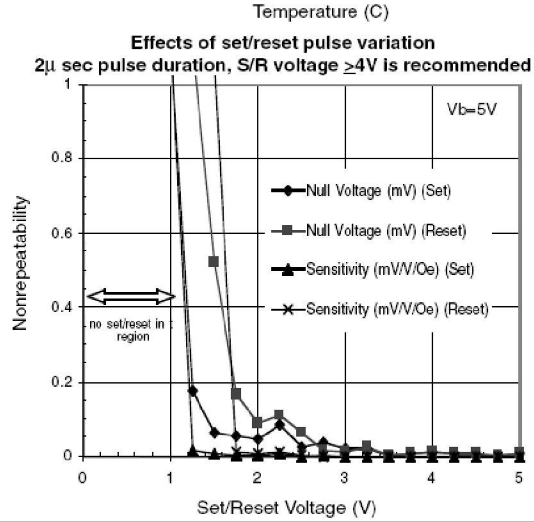












Appendix I:
Honeywell HMC1023 Three-Axis Magnetoresistive Sensor Datasheet

HMC1023

SENSOR PRODUCTS

SPECIFICATIONS

Characteristic	Conditions	Min	Typ	Max	Unit
Bridge Supply	Vbridge referenced to GND	3	5	12	Volts
Bridge Resistance	Bridge current = 5mA	250	350	450	Ω
Operating Temperature	Ambient	-40		125	° C
Storage Temperature	Ambient, unbiased	-55		125	° C
Field Range	Full scale (FS) — total applied field	-6		+6	gauss
Linearity Error	Best fit straight line (at 25° C) ±1 gauss ±3 gauss ±6 gauss		0.05 0.4 1.6		%FS
Three-Axis Orthogonality	Angle from 90°		±1		degrees
Hysteresis Error	3 sweeps across ±3 gauss @ 25° C		0.08		%FS
Repeatability Error	3 sweeps across ±3 gauss @ 25° C		0.08		%FS
Bridge Offset	Offset = (OUT+) - (OUT-), Field=0 gauss after Set pulse, Vbridge=5V	-10	±2.5	+10	mV
Sensitivity	At Vbridge=5V	0.8	1.0	1.2	mV/V/gauss
Noise Density	Noise at 1Hz, Vbridge=5V		48		nV/√Hz
Resolution	Bandwidth=10Hz, Vbridge=5V		85		μgauss
Bandwidth	Magnetic signal (lower limit = DC)		5		MHz
OFFSET Strap	Measured from OFFSET+ to OFFSET-	40	50	60	Ω
OFFSET Strap ΩTempco	TA=-40 to125° C		3900		ppm/° C
OFFSET Field	Field applied in sensitive direction	4.0	4.6	6.0	mA/gauss
Set/Reset Strap (1)	Measured from S/R+ to S/R-	2.0	3.0	4.0	Ω
Set/Reset Current (1)	2μS current pulse	1.5	2.0	4.0	Amp
Disturbing Field	Sensitivity starts to degrade. Use S/R pulse to restore sensitivity.	20			gauss
Sensitivity Tempco	TA=-40 to 125° C Vbridge=5V Ibridge=5mA	-2800	-3000 -600	-3200	ppm/° C
Bridge Offset Tempco	TA=-40 to 125° C no Set/Reset Ibridge=5mA with Set/Reset		±500 ±10		ppm/° C
Resistance Tempco	Vbridge=5V, -40 to 125° C		2500		ppm/° C
Cross-Axis Effect	Cross field=1gauss (see AN-205) Happlied=±1 gauss		+0.3		%FS
Max. Exposed Field	No perming effect on zero reading			200	gauss

(1) Three in parallel.

Units: 1 gauss (G) = 1 Oersted (in air), 1G = 79.58 A/m, 1G = 10E-4 Tesla, 1G = 10E5 gamma

Honeywell

900252-Rev A
02/00

Appendix J: Logitech QuickCam Express Datasheet

Logitech

QuickCam® Express

PC • USB

Easy to use and economical. Great for video e-mails and face-to-face video calls. Plus you can add live video to Yahoo! Messenger.

Now you can meet face-to-face online with live video calls. Or make your instant messages come alive by adding live video to your Yahoo! Messenger, MSN® Messenger and AOL Instant Messenger℠ (AIM). Or set up a webcam to share your world. Or snap and send photos and video along with your e-mail as easily as you send text. All you need is QuickCam® Express and the Internet.

- Easy to share videos and still images
- Simple set-up: install the software, plug it in, and start shooting
- Snap button for instant pictures and photos

The Simple Way to Get Closer™

- Add live images to your instant messages
- Meet face-to-face online with video calls
- Capture stills and videos
- E-mail photos and video quickly
- Set up a webcam, create a web album
- Broadcast live video over the web
- Play cool camera games
- Two-year limited hardware warranty

Software:

- One click video e-mail software
- Webcam-enabled Yahoo! Messenger
- SpotLife™ Personal Video Broadcasting
- SpotLife™ Web Album Creator Software
- SpotLife™ Web Cam Software
- Reality Fusion® GameCam SE™ and screen saver software
- Logitech® Smart Internet Updater™

Appendix K:
Team Members' Vitae